

## **Shear strength behavior of barind soil on triaxial extension stress path tests**

S.A. Mofiz

Department of Civil Engineering, Rajshahi University of Engineering & Technology, Bangladesh

M.M. Rahman

Department of Civil and Natural Resources Engineering, University Canterbury, New Zealand

**ABSTRACT:** In this study computer control hydraulic geotechnical digital system (GDS) triaxial equipment used for the evaluation of shear strength behavior of the barind (expansive) soil in tensile stress path test. The testing program intense on the study of normally consolidated drained triaxial extension tests on sample size 50 mm diameter and 100 mm high compacted barind (expansive) soil. Testing was carried out at consolidation pressures ranging between 100–500 kPa. The unload-reloading tests were done at confining pressure 200 kPa for the determination of unload-reload model constants. The non-linear elastic model parameters for the compacted expansive soil were determined from these tests. An attempt is made to verify the model parameters by comparing numerical predictions with the experimental test results. Numerical analysis using hyperbolic model parameters indicated good agreement with the experimental results.

## **1 INTRODUCTION**

In tropical and semi-tropical areas, compacted soil have been used as a standard practice in geotechnical construction works to improve the settlement characteristics of foundation, stability of slope, and embankments as well as seepage control in the dam cores. Most of the research work that exists in the literature aimed at setting guidelines to ensure the satisfactory performance of the soil materials under compression and shear. The practice of neglecting the tensile strength of soils in most stability analysis has led to an almost absence of the test data on the behavior of soils in the negative effective stress range. Geotechnical engineers commonly adopted conventional triaxial compression tests data in design practices in dealing with the slope stability and embankment problems on compacted soil, but most of them ignore tension test of such soil. However, tensile stress regimes are encountered in many geotechnical structures such as rigid and flexible layer pavements, in the upper part of the natural and compacted slopes, and in the dam cores. In the Barind tract of Bangladesh a large number of civil engineering structures were built on highly plastic (expansive) soils before the 1980s are now showing signs of deterioration. This deterioration which is make known by swelling and cracking of the superstructure, due to shrinkage which was no considered during construction work. This paper describes the detailed description of the use of hydraulic triaxial test apparatus for the evaluation of tensile stress-strain properties of compacted barind soil. The non-linear model has been used for the model prediction of tensile stress-strain behavior of the barind soil.

## **2 RESEARCH BACKGROUND**

Barind soil can be found in major parts of the northern region of Bangladesh and has been used as a low cost construction material for many years. Its availability at and around construction sites and the resulting reduction in transportation costs are the primary practical factors. A review of the previous work indicated that most tension tests on soils have been to determine tensile strength rather than stress-strain characteristics. Conlon (1966) first reported tension test on soils in the triaxial equipment. Bishop and Graga (1969) explained the feasibility of performing tension tests in triaxial equipment by employing specimens with reduced central sections. Parry and Nadarajah (1974) reported tension tests under undrained conditions with pore water measurement. Ajaz and Parry (1975) reported that the soil under tensile stress fields exhibit non-linear behavior. Al-Husssaini (1981) also performed tests using triaxial set up in which the failure mechanism was achieved under a stress system with one of the principal stresses being tensile in character. Berdie (1991) carried out tension test of non-uniform cross-section test specimens and investigated the tensile stress-strain behavior of

kaolin within the framework of established constitutive relations under an axi-symmetric (conventional) stress system. This paper will focus on the tensile stress-strain properties of barind (expansive) soil and to determine the non-linear model parameters. These model parameters play important roles in predicting tensile forces in tension governing pavement and foundation problems on barind soil.

## 2.1 Stress path

In the field soil element undergoes different stress paths depending upon the loading conditions. All of these stress paths lie on a triaxial plane and are shown in Figure 1. Considering the geometry of the potential failure surface, weighting factors may be applied to derive the appropriate strength to use in the limiting equilibrium analysis for a given field stress path.

## 2.2 Soil properties

Barind soils are often found in tropical or semi-tropical area such as in northern district of Bangladesh. Disturbed and undisturbed soil samples were brought from a site in Godagari Upazilla of Rajshahi district, Bangladesh. The soil is classified as CH according to the Unified Soil Classification (USCS) System. The basic soil properties were determine following the ASTM Standard (2000). The soil is radish in color and classified as CH in Unified Classification System (USCS). The soil particle contains about 70% clay, 25% silt and 05% sand. The other soil properties are: liquid limit 71%, plastic limit 30% plasticity index 41%, and specific gravity 2.72. From the plasticity chart, as suggested by Head (1980), the soil can be classified as CH i.e. high plasticity clay. The natural moisture content was about 34.2%. The coefficient of permeability of compacted residual soil was found to be approximately  $2.462 \cdot 10^{-9}$  m/sec and it indicate that the permeability of the soil is very low (Terzaghi & Peck, 1948; Whitlow, 1994).

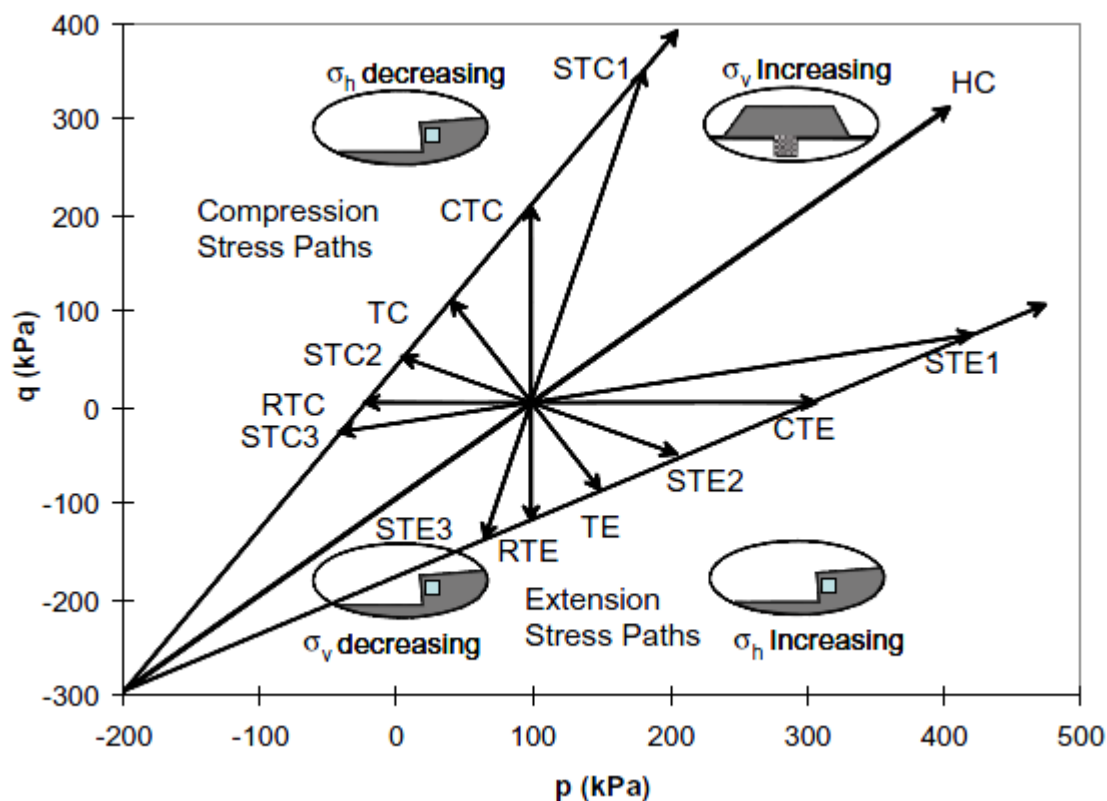


Figure 1. Schematic representation of the different triaxial stress paths.

## 3 SAMPLE PREPARATION AND TESTING

Disturbed sample of the barind soil with 95 percent silt and clay fraction was used in this investigation. The soil was first dried under laboratory air-dry conditions, then ground and passed through 2 mm sieve. The dry powder was carefully wetted with a spray gun to the standard optimum moisture content. The moist soil was then stored in several sealed plastic bags in moist room for about a week before use. In order to get the best possible standard homogeneity,

compaction was performed in three layers in a 50 mm diameter and 100 mm high special type of splitting cylindrical mold. A rate of 0.15 mm/min for compression on a triaxial press was adopted, and each layer was compacted following the approach (Cui and Delage, 1996) to ensure Proctor maximum density and moisture content with a double piston system.

### 3.1 Triaxial apparatus

The triaxial extension cell is based on the design of Bishop and Wesley's (1975) hydraulic triaxial apparatus for controlled stress path testing developed at Imperial College of Science and Technology, London. Axial force is exerted on the test specimen by means of a piston fixed to the movable base pedestal. The top cap of the test specimen is fixed in position by an adjustable rod passing through the top of the cell. The piston moves vertically up and down

in a linear guide comprising a cage of ball bearings housed in a turret joining the cell to the base. The piston is actuated hydraulically from an integral lower chamber in the base of the cell which contains deaerated water. The piston is sealed into the upper cell and the lower chamber by matched Bellofram rolling diaphragms, which sweep equal volumes of water. The extension device is fitted to the triaxial cells in place of the redundant load cell and following the approach (Mofiz 2000). The object of the extension device is to allow axial stress to be reduced below radial stress. The photographic view of the hydraulic triaxial apparatus with extension test arrangement is shown in Figure 2. Fixed the bottom of the rod is a truncated conical fitting which mates with the plane top cap of the triaxial test specimens. The top cap is fitted with a bell mounted surgical PVC dip molded sleeve. The cell is filled with water,

with air being purged out through the hollow reaction rod. The reaction rod is then adjusted to dock the plane and conical parts together. Lightly smearing the angled surfaces with soft silicone grease ensure good contact. A small suction can then be applied to the top of the hollow reaction rod to cause the sleeve to seal the interface. Cell pressure is then applied. As the top cap is now sealed to the fixed reaction rod, cell pressure does not act vertically on the test specimen.



Figure 2. Photographic views of GDS triaxial testing system and setting arrangement of triaxial extension test specimen.

Table 1. Testing programs of triaxial extension stress paths.

Stress paths	Test no.	Water content (%)	Soil density (kN/m <sup>3</sup> )	Consolidation pressure (kPa)		Stress coordinates at shearing (kPa)			Remarks
		w	$\gamma_d$	$\sigma_c$	Bp	$\sigma_1$	$\sigma_3$	Bp	
CTE	1	24.95	16.58	150	50	850	150	50	Stress control
	2	24.96	16.63	250	50	1050	250	50	
	3	25.00	16.54	350	50	1250	350	50	
	4	24.98	16.49	450	50	1450	450	50	
TE	1	24.97	16.66	150	50	50	200	50	Stress control
	2	24.95	16.51	250	50	50	350	50	
	3	25.01	16.47	350	50	50	500	50	
	4	25.07	16.53	450	50	50	650	50	
	5	25.06	16.49	550	50	50	800	50	
RTE	1	24.95	16.42	150	50	50	150	50	Stress control
	2	24.98	16.51	250	50	50	250	50	
	3	24.91	16.50	350	50	50	350	50	
	4	24.93	16.59	450	50	50	450	50	
	5	25.00	16.61	550	50	50	550	50	

### 3.2 Testing program

The triaxial testing programs for compacted barind soil are divided into three stress paths. The stress paths used in the drained triaxial testing are Conventional Triaxial Extension, CTE; Reduced Triaxial Extension, RTE; and Triaxial Extension, TE. Details of extension stress paths testing program for barind soil are presented in Table 1. All the tests were carried out at effective consolidating pressure varying from 150–550 kPa. and back pressure 50 kPa.

## 4 RESULTS AND DISCUSSION

In this study, three triaxial extension stress path tests, i.e. CTE, TE and RTE were conducted. The shear stress versus axial strain and volumetric strain versus axial strain for the various stress paths at consolidation pressures ( $\sigma_c$ ) between 100 kPa to 500 kPa are shown in Figure 3 to Figure 5. As in the case of compression loadings, the stress-strain relationships are nonlinear and the failure strains increases with the increase in confining pressure for all the stress paths. Similarly, the  $\epsilon_v$ - $\epsilon_a$  curves do not produce any distinct peak points. The volume change characteristics for the conventional triaxial extension (CTE) paths exhibit contraction volume change behaviour at lower stress levels and the rate of contraction decreases at higher stress levels. In these cases, the volume contraction is more noticeable than other stress paths. The main reason of this behaviour may be due to gradual increase of confining pressure until failure. The TE stress path test results show significantly lower volume contraction than CTE stress paths. On the other hand, for RTE stress path the volume expansion increases at lower stress level and the rate decreases at higher stress level. Taha et al. (1999) reported similar behaviour in drained triaxial extension test on residual granite soil. Thus, the failure stress and the volume change behaviour for triaxial extension tests are also stress path dependent. RTE stress path test results indicate that the axial strain corresponding to maximum stress increases with confining pressure and the volumetric strain exhibits a dilative behaviour Figure 5. This dilative behaviour can be explained, in part, by the volume change of consolidated saturated soil during the application of tensile stress. In most cases, the specimens behave as strain softening failure material. The failure of the test specimens is observed at the mid height due to necking for all the triaxial extension tests (Figure 6). The failure envelope (best-fit straight line to the data points) indicates a frictional-cohesive behaviour

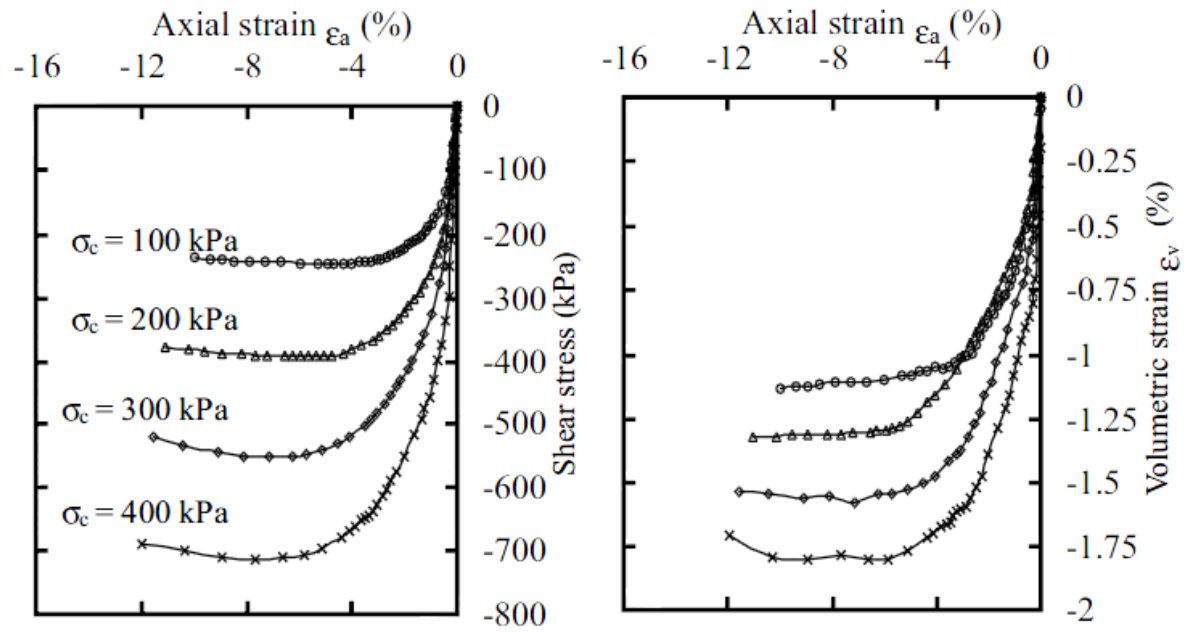


Figure 3. Stress-strain and volume change behavior of barind soil for CTE stress path.

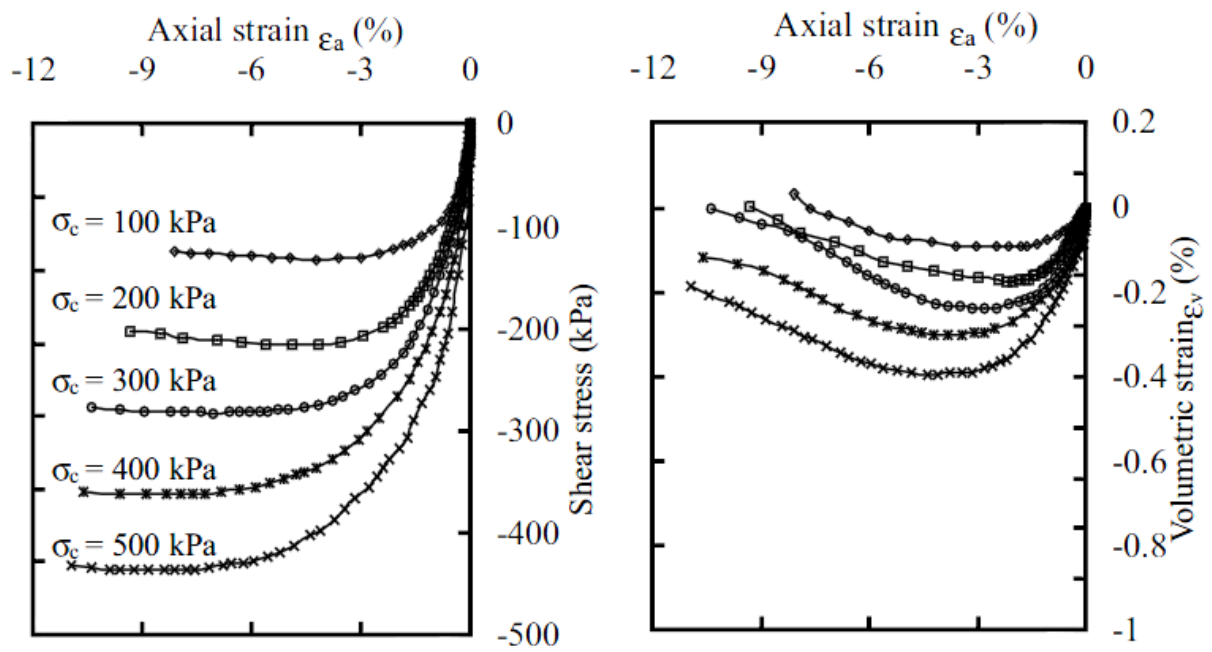


Figure 4. Stress-strain and volume change behavior of barind soil for TE stress path.

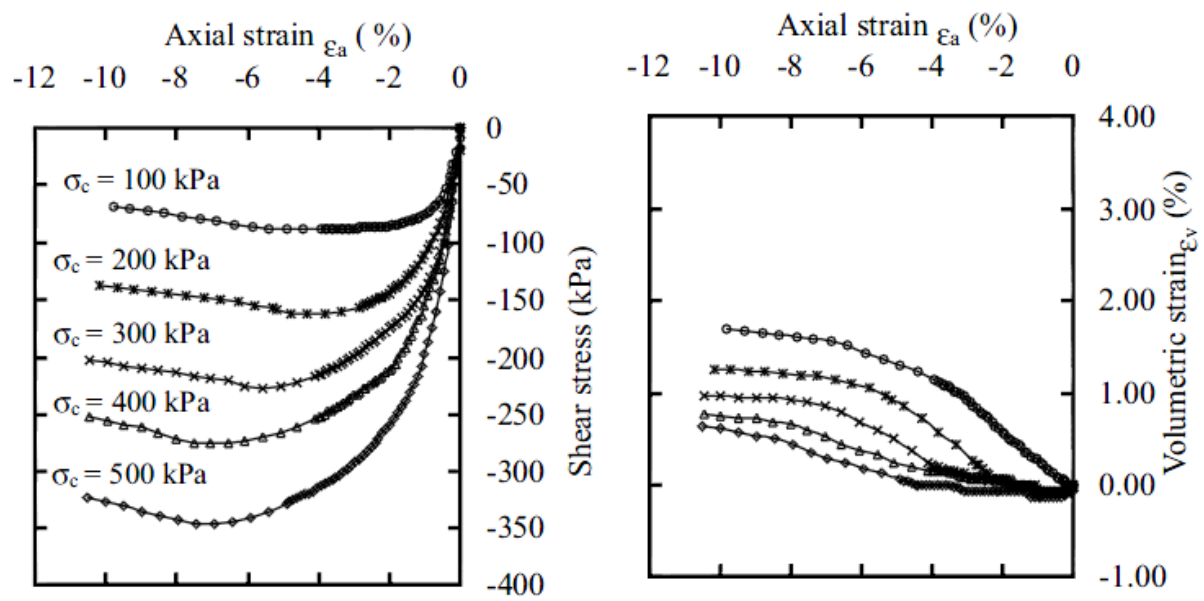


Figure 5. Stress-strain and volume change behavior of barind soil for RTE stress path.



Figure 6. Failure pattern of triaxial extension test specimen in GDS triaxial testing system.

Table 2. Elastic constants of barind soil for various extension stress paths.

Test loading condition	Type of stress paths	Confining pressure (kPa)	Elastic parameters		
			K	n	$R_r$
Extension	CTE	150 to 450	250	0.97	0.85
	TE	150 to 550	170	0.79	0.84
	RTE	150 to 550	151	0.74	0.85



with strength parameters in terms of effective stresses in which  $\phi' = 23^\circ$  and  $c' = 31$  kPa. The non-linear elastic model parameters for barind soil are then determined for the various stress paths. The elastic parameters are obtained following the procedures outlined by Duncan et al. (1980). Boscardin et al. (1990) also followed the same procedure to determine the elastic and bulk modulus for compacted soil. The test results showed higher initial tangent modulus in CTE stress path and lower value for RTE stress path. It can be concluded that the elastic parameters are also dependent on the stress paths. The elastic constants of barind soil for extension stress paths are presented in Table 2. Similarly, the variation of modulus and exponent number is such that it shows the highest under CTE and lowest values under RTE paths. This follows the values of the failure strains and also dependent on the loading conditions (stress path). It is also observed that there is no significant variation of the failure ratio ( $R_f$ ). The non-linear elastic model parameters for compacted barind soil fill material were then determined from these tests. The effective stress hyperbolic and Mohr-Coulomb strength parameters were obtained following the procedure outlined by Duncan et al. (1980). The unload-reload modulus number, bulk modulus number and bulk modulus exponent of barind soil for extension are  $K_{ur} = 198$ ,  $K_b = 93$  and  $m = 0.5$  respectively.

For tests at confining pressure 200 kPa, the samples were unloaded at stress levels (ratio of maximum deviator stress to unloading stress) of 0.90 and 0.96 for drained test. The results of multiple unloading and reloading tests for barind soil is shown in Figure 7. It is observed that for cycles of unloading-reloading, the barind soil maintains a small amount of hysteresis. Furthermore, the modulus for both cycles of unloading-reloading are the same, even though they occur at different strains and stress levels. On the basis of these observations, it seems reasonable to believe that the stress-strain behaviour of barind soil on unloading and reloading may be approximated with a high degree of accuracy as being linear and elastic. Because this linear behaviour is independent of the value of stress difference, the representative modulus value is dependent only upon the confining pressure. The  $E_{ur}$  were obtained from the best-fit straight line at the stress-strain plot (Figure 7). Analysis was made to verify the model

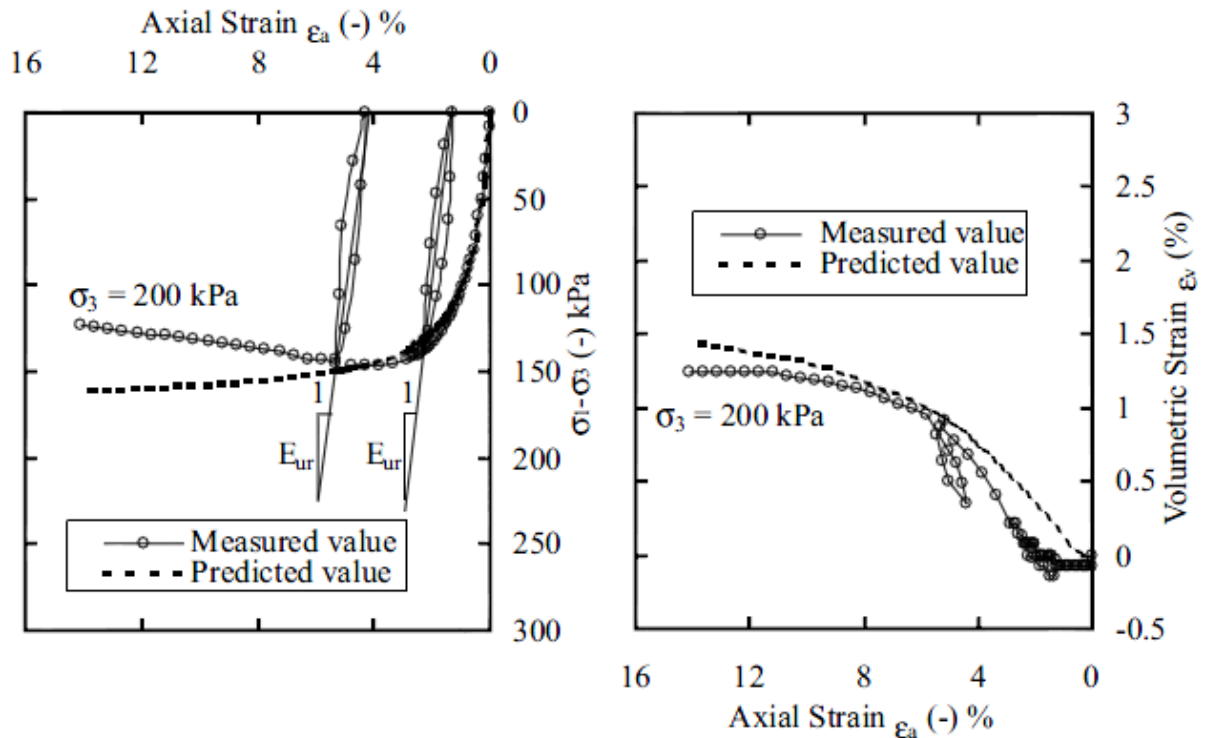


Figure 7. Measured and predicted behavior of unload-reload drained triaxial extension test.

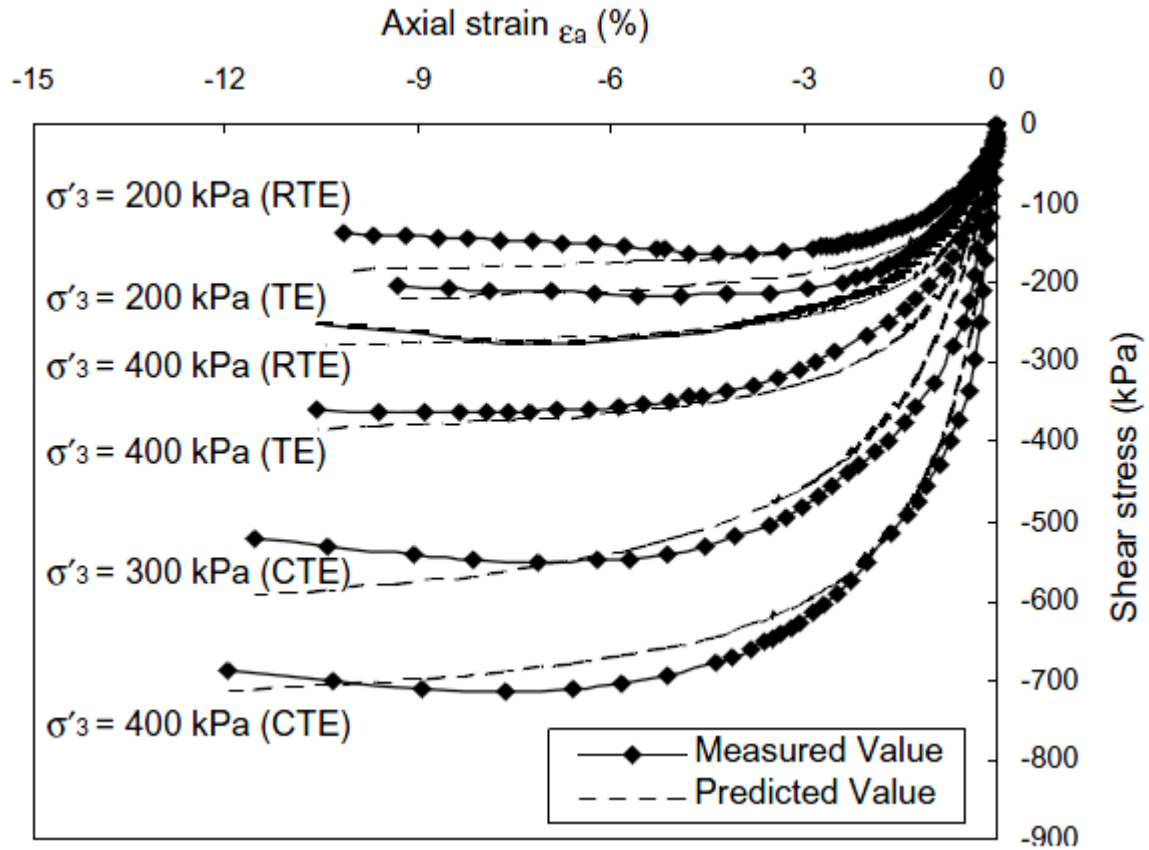


Figure 8. Measured and predicted stress-strain behavior of drained triaxial extension stress path tests.

parameters by comparing numerical predictions with the experimental triaxial extension test results. The measured and predicted stress-strain curve for drained triaxial extension tests is shown in Figure 7. In addition, the stress-strain prediction for test without unloading cycle is shown in Figure 8. In order to check the sensitivity of the model parameters, the modulus number and modulus exponent were varied up to  $\pm 5\%$ . Within this range, the results exhibit that there is no significance difference in the predicted response. On the other hand, if this tolerance is more than  $\pm 5\%$ , then the predicted behavior deviated from the measured values. Thus, it is important that these parameters be obtained as accurate as possible since deviation of 5% or more can lead to deviation in the predicted behavior. Increasing the stress ratio,  $R_r$ , (maximum of 1.0) also provided a better estimate of the triaxial stress-strain relationships.

## 5 CONCLUSIONS

A series of drained triaxial extension stress path tests was conducted on compacted barind soil. Test results showed that different types of stress paths increased shear strength and stressdeformation characteristic changes with the increase of confining pressure. At low strains, soil system shows similar extension stiffness parameters for drained tests. The test results indicate that soil specimen fail at axial strains at 4 to 8%, which is dependent on confining pressure during testing. The test observations also indicate that in most cases soil specimen exhibits strain-softening behavior and are highly dependent on the applied stress path. The non-linear elastic model parameters for barind soil are then determined for the various stress paths. The test results showed higher initial tangent modulus in CTE stress path and lower value for RTE stress path. This is due to fact that the lower value of failure strain was found for CTE path in comparison to the RTE path. It can be concluded that the elastic parameters are also dependent on the stress paths. The unload-reload elastic parameters such as modulus number, bulk modulus number and bulk modulus exponent of barind soil are determined. Theoretical analysis using the hyperbolic model indicates good agreement with the experimental results.



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